Routing Medical Images with Tabu Search and Simulated Annealing: A Study on Quality of Service

Mejía M. Paula, Ramírez L. Leonardo, Puerta A. Gabriel

***Abstract*—**In telemedicine, the image repository service is important to increase the accuracy of diagnostic support of medical personnel. This study makes comparison between two routing algorithms regarding the quality of service (QoS), to be able to analyze the optimal performance at the time of loading and/or downloading of medical images. This study focused on comparing the performance of Tabu Search with other heuristic and metaheuristic algorithms that improve QoS in telemedicine services in Colombia. For this, Tabu Search and Simulated Annealing heuristic algorithms are chosen for their high usability in this type of applications; the QoS is measured taking into account the following metrics: Delay, Throughput, Jitter and Latency. In addition, routing tests were carried out on ten images in digital image and communication in medicine (DICOM) format of 40 MB. These tests were carried out for ten minutes with different traffic conditions, reaching a total of 25 tests, from a server of Universidad Militar Nueva Granada (UMNG) in Bogotá-Colombia to a remote user in Universidad de Santiago de Chile (USACH) - Chile. The results show that Tabu search presents a better QoS performance compared to Simulated Annealing, managing to optimize the routing of medical images, a basic requirement to offer diagnostic images services in telemedicine.

***Keywords*—**Medical image, QoS, simulated annealing, Tabu search, telemedicine.

I. Introduction

THE infrastructures for the provision of services in telemedicine requires better technologies each day; thanks to the increase in their variety and complexity, said technologies must guarantee the speed and access to the information from any place and location [1]. Additionally, the health entities expect for a telemedicine network to be a support when offering a service, in this case, the download or upload of medical images (DICOM). It is worth mentioning that the transmission of medical information using communication systems and technologies, allows to obtain the benefits in the health field to satisfy the criteria of QoS and supply the needs of the users [2], [3].

This study focused on the manipulation of clinical information, in other words, information with a high degree of sensibility, because it does not only involve information or data, but also involves the health and wellness of people. Therefore, the availability and integrity criteria must be guaranteed for said information.

The availability guarantees that information is always available to the specialists, patients or qualified individuals that require it, regardless of time or place. This criterion is very important, because if this fails, it may delay a procedure that requires immediate attention, affecting the life and health of the patient. The integrity guarantees that the consulted information is accurate and has not been modified, this is important because a medical diagnosis may be changed, a medical procedure that is not needed may be performed and this will affect the patient. Thanks to this need, this study tries to evaluate and implement heuristic algorithms in a telemedicine network, since these will allow us to obtain a route in the smallest possible time and meet the optimal levels in accordance with the criteria required for its functioning, in accordance with the information that is being handled [4], [5]. This previous statement refers to the medical images that are seen by the specialists and patients, fulfilling the service and performance quality parameters, guaranteeing an efficient telemedicine system that satisfies the needs of both the patient and the health entity. With the purpose of developing a clear and optimal way to do this, the study conducted the characterization of metrics and variables used for the evaluation of the system, the implementation of tests scenarios under different conditions, and the comparison and evaluation of the performance from the QoS parameters from two routing heuristic algorithms, implemented in the connectivity system from telemedicine services. Additionally, to guarantee that this system meets the different parameters and criteria established before and to ensure the efficient operation in the medical images routing, the TIGUM group has established an agreement with the Universidad Santiago de Chile, where different connectivity tests were conducted in a remote manner, which allowed us to broaden the perspective of the functioning we have for this study.

II. Methodology

A descriptive methodology was implemented, which allowed the collection of data and key factors that helped in the development of this project, where the service quality metrics were characterized, the routing algorithms that were going to be implemented were defined and the variables that significantly contributed to the development of the study were determined. Besides this, an analytical methodology was implemented, where a comparison of the previously selected routing

Mejia. M. Paula is a research assistant of TIGUM research Group of Universidad Militar Nueva Granada, Bogotá, Carrera 11 No.101-80, Colombia (phone: +51 3188808889; e-mail: u1401113@unimilitar.edu.co).

Ramírez L. Leonardo is a researcher and director of TIGUM research group of Universidad Militar Nueva Granada, Bogotá, Carrera 11 No.101-80, Colombia (phone: +51 0316500000; e-mail: tigum@unimilitar.edu.co).

Puerta A. Gabriel is PhD student and researcher of TIGUM research group of Universidad Militar Nueva Granada, Bogotá, Carrera 11 No.101-80, Colombia (phone: +51 3115987518; e-mail: u7700110@unimilitar.edu.co).

algorithms was made and through statistical methods the analysis was made to determine which algorithm had the best performance regarding the QoS metrics and efficiency of the routing of medical images. As the first stage from this project, the QoS metrics were established, which were considered for the evaluation of the telemedicine system. A background search of authors that focused on the same knowledge area was conducted, with the purpose of looking for the relevant metrics that were used in this study and additionally finding the research gap, to which we expect to contribute knowledge and advancements.

Once said metrics were established, different test scenarios were proposed locally and remotely. For this purpose, we used the network monitoring tool Wireshark, which allowed us to analyze the behavior of the servers from the TIGUM group by measuring the metrics and system evaluations with different established parameters.

With the purpose of analyzing the connectivity metrics and parameters with the Universidad Santiago de Chile, different test scenarios from said city were evaluated and the channel with the Universidad Militar Nueva Granada in Bogotá was characterized. For this we conducted measurements at different hours from the day, managing to determine how the channel behaves in the upload and download of medical images (DICOM) from Santiago de Chile with different traffic conditions.

To conduct the comparison and evaluation of the routing algorithms, a simulation was made in the Net2plan software, which allows modeling of the specific network topology for this study and the configuration of the previously established parameters in the environment of provision of telemedicine services.

With the purpose of collecting the measurement results in a clear an organized way, we used the Excel tool and to illustrate the results we graphed them using the MATLAB tool.

The work environment from the TIGUM group for the implementation of the telemedicine system is composed by a web server and a repository server that stores the medical images (DICOM). In this environment, the conditions of the network were modeled, the routing algorithms for medical images were evaluated and the connection was made through a tunnel with the Universidad de Santiago de Chile (Fig. 1)

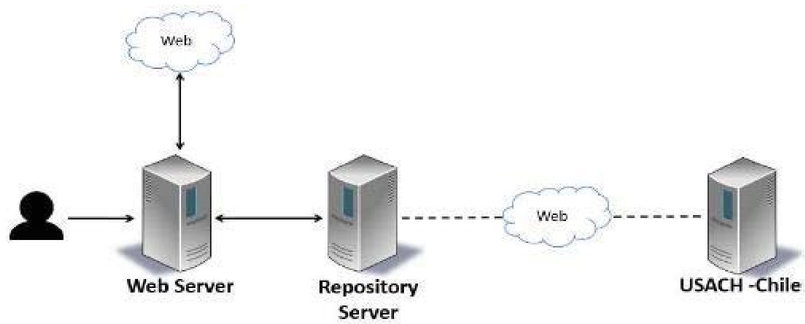


Fig. 1 Network architecture, taken from self-made model

III. Variables for System Evaluation

In this study we defined service quality metrics for the performance evaluation of the telemedicine system and the routing algorithms, since these allow determining the reliability, speed, stability and efficiency of the service. These parameters are essential for the fulfillment of the availability and integrity criteria, which must be guaranteed in this type of data and applications. The determined metrics were:

A. Delay

The delay determines how slow/fast the package will arrive. In other words, it is the processing time from the receiver/ transmitter and the total transmission time. The greater this value is, the greater is the probability of loss of information, in other words, this parameter guarantees how reliable the service is.

$$\text{Delay} = Arrival\ time - Exit\ time \tag{1}$$

B. Latency

Latency is the time interval the package is expected to take from the moment it was received and the moment it was sent. It is also known as the delay average and determines how fast the service is.

$$\text{Latency} = \sum_{j=0}^{n} \frac{Delay(j)}{n} \tag{2}$$

$$\text{Latency} = E(Delay) \tag{3}$$

C. Jitter

It is the difference between the value of expected arrival time from a package and the time in which it arrives. This metric determines the stability of the service.

$$\text{Jitter} = |Delay\ of\ the\ package - Latency| \tag{4}$$

D. Throughput

It is the amount of data that arrive in a link without package loss, in other words, the success rate in the delivery of a package in a unit of time. It is measured in Mbps and determines how efficient the service is.

$$\text{TH} = \frac{Received\ packages}{time} \tag{5}$$

E. Network Use

The network use determines the availability of the routes and wavelengths to attend future incoming requests; it is measured in percentage and determines the availability of the service.

IV. Description of the Algorithms

As mentioned before, the heuristic algorithms allow the adaptation to the different implementation systems, due to their high flexibility and performance in the routing of information. The following are types of heuristic algorithms: Tabu search [6], [7], genetic algorithms [8], simulated cooling [9], GRASP [10] and ant colonies [11], [12], which are based in the search and optimization of the times related to the data routing.

For this paper, we used the Tabu Search and simulated annealing algorithms and we compared the results based on the QoS metrics and the parameters established before.

A. Tabu Search

The Tabu Search algorithm was designed by Glover and Hansen in 1986 to solve combinatorial optimization problems [13]. It is characterized by the way in which it finds possible solutions quickly and its flexible memory. It also penalizes all actions that move away from the current solutions and keeps the 'neighborhoods' that have high chances of containing a solution. This algorithm implements a Tabu list that stores the solutions visited in an iteration and considers them as a non-potential neighbor, which means it has a short-term memory and remembers the recent solutions, so it will not repeat them and instead will explore new regions from the search space [13], [14]. This algorithm was modeled using a pseudo-code, which explains its functioning. (Fig. 2)

```
Main
{
x = x0 // current solution equal to the initial solution
x (best) = x0 //The best solution so far, equal to the initial solution
TL = ∅ // taboo list initially empty
}
While the criteria of stopping in the external loop are invalid
Do
{
xBestNeighbor= // initializes the best neighbor of this solution
For each v neighbor of x
Do
{
Si a (v) ∊ TL // if the neighbor has an attribute in the taboo list, skip it
Si c (v) < c (xBestNeighbor)
Entonces xBestNeighbor = v // The neighbor solution v improves the current solution x
}
x = xBestNeighbor// move to the best neighbor that does not belong to the TL
TL = TL + a (xBestNeighbor) // agregar al TL el atributo de la nueva solución
If size TL > tabu tenure
So delete the oldest element in the TL
If c (xBestNeighbor) < c (xbest)
So xbest = xBestNeighbor updates the best solution found so far
}
Return (xbest)
```

Fig. 2 Pseudo-code from the Tabu Search algorithm

```
Main
{
x = x0 // current solution equal to the initial solution
xbest = x0 //The best solution so far, equal to the initial solution
T = T0 // Initial temperature
}
While the criteria of stopping in the external loop are invalid
Do
{
While the criteria of stopping in the external loop are invalid
Do
{
v = neighboring solution of x randomly chosen
Δc= c(v) - c(x)
if Δc <0
so
{
// the neighboring solution v improves the current situation x
x=v
If c (v) < c (xbest)
so xBest = v
}
else if x = v, with probability e^ (-Δc/T)
}
T =  αT // reduce temperature
}
Return (xbest)
```

Fig. 3 Pseudo-code from the Simulated Annealing algorithm

B. Simulated Annealing

This algorithm was proposed by Kirkpatrick in 1983 and is based on the analogy of the annealing of solids [13], which consists of the technique of heating a solid and the slowly cool it, producing the variation of its physical properties and the heat causes the increase of energy from the atoms so they can move from their initial positions. When they slowly cool, they can return to their initial position using less energy. Said principle is used to solve optimization problems [13].

The Simulated Annealing algorithms are iterative, in other words, in each repetition from the algorithms there is a variation from one solution to the problem to another one. A current solution is provided, and a neighbor solution is chosen, if the cost of the neighbor solution is better it turns into the current solution. If it is the opposite, it is possible to accept the neighbor solution as the current one if the probability that results from the following equation is met.

$$P = e^{-\frac{c(v)-c(x)}{T}}$$

where: C (v) = cost of the neighbor solution; C (x) = cost of the current solution; T = Temperature (global variable from the system).

In this probability the following happens, the greater the temperature, the bigger is the probability of accepting a neighbor solution as a current one, even if it has a greater cost [15]. Likewise, this algorithm was modeled through a pseudo-code, which explains its functioning (Fig. 3).

V. Development

Once the environment and work methodology were established, as well as the metrics mentioned before, different test scenarios were implemented, which allowed us to know the quality of the service that the telemedicine system presents and we were able to characterize the channels for the subsequent offering of the service for the routing of medical images, knowing the network environment where the routing algorithms were implemented. This guaranteed that said algorithms were modeled for this environment specifically and that they fulfilled its requirements.

A. Test Scenario 1

In the first scenario, a stress and load test was conducted using the JMeter tool, which allowed to upload and download images through a script, modifying the number of users. The variation was made between 1, 10, 100, 200 and 1000 simultaneous users, where for each iteration, the error percentage in the reception of the packages was analyzed. It was determined that the system presents a percentage error of less than 1% up to 100 users, in other words, the system handled up to 100 simultaneous users. Once we obtained the data, we conducted tests with 100 users and for 10 minutes the behavior from the QoS metrics from the channel between the web server and the repository service was measured simultaneously (Fig. 4), during the load and download of 40 MB medical images. These tests were made with the purpose of having a reference framework for future measurements, since the channel that is being measured has a direct connection at microns of distance, which provided us with ideal value results.

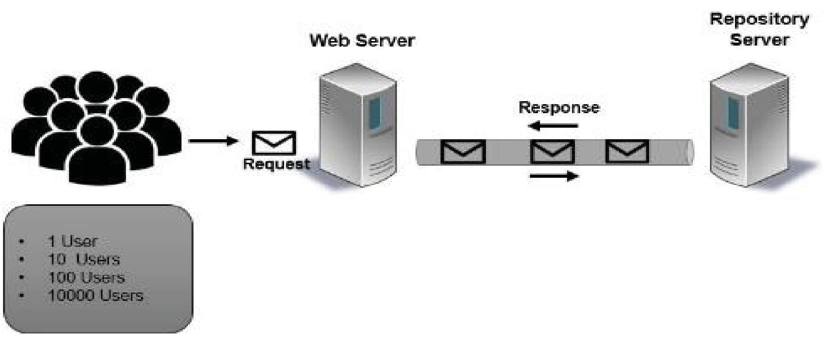


Fig. 4 Test scenario 1

Fig. 5 Test scenario 2

B. Test Scenario 2

The second scenario is conducted with the amount of users that the system can support in scenario 1, evaluating the metrics for the QoS that the system presented when the upload and download of medical images were made from a remote user (for 10 consecutive minutes), considering that said user makes the request for the image from the web server and this one makes the request to the repository server. The behavioral analysis for the channel between the remote user and the web server, and the channel between both servers with these specific parameters were conducted (Fig. 5).

C. Test Scenario 3

In the third scenario, we observed the behavior of the QoS metrics when 40 MB medical images are being uploaded and downloaded by users connected in a local and remote way (Fig. 6).

The purpose of this is to analyze how two channels behave, offering the service simultaneously and guaranteeing that the servers and channels can handle the quantity of established users, no matter how they are connected.

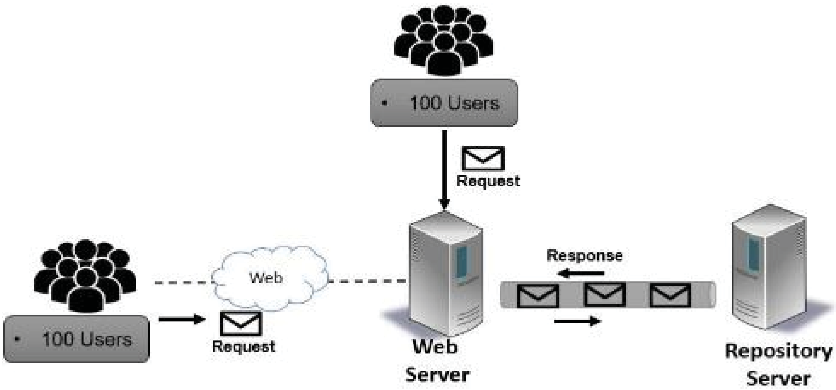


Fig. 6 Test scenario 3

D. Channel Characterization

Upload and download tests for 40 MB medical images were conducted, making the request from the USACH to the repository server of the UMNG - Bogotá, where said images are stored (Fig. 7).

Additionally, two scripts created on the web server for this purpose were used. Said scripts conducted a SSH connection between the remote user located in Chile and the repository server in Bogotá, thus creating a tunnel between them, allowing the measurement of the QoS metrics and the routing of the images. Said tests were conducted at different times of the day, with the purpose of characterizing said channel with different traffic conditions and guaranteeing its optimal connectivity. For these tests, the TCP and HTTP packages were analyzed, both for the upload and the download of medical images.

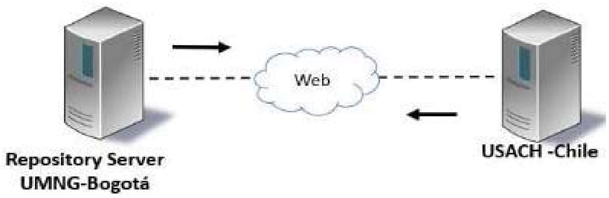


Fig. 7 Scenario for the characterization of the Bogotá-Chile channel

E. Implementation of Routing Algorithms

Once the behavior of the system is known under different conditions and the channels for the offering of the service are characterized, the modeling of the network topology and the work environment is made in the Net2plan simulation tool.

Net2plan is an optimization tool for networks with a great flexibility, since it allows the simulation and implementation of a great variety of technologies, new routing algorithms can be developed in this tool with unique network designs for each user. Additionally, it has the option of generating different types of reports that allow the evaluation of the network regarding different parameters for each specific design [16].

Thanks to the characteristics offered by the simulation tool mentioned before, the network design for the evaluation of the Tabu Search and Simulated Annealing algorithms in the telemedicine system is modeled. It uses the servers located in Bogotá, Colombia, the remote user located in Santiago de Chile, Chile and the intermediate nodes through which the routing of medical images was made (Fig. 8).

Once the network design is implemented and established, we observe the distribution of the nodes and established links between them, provided by the tool (Fig. 9), with the purpose of being clear when configuring the specific parameters for each of them.

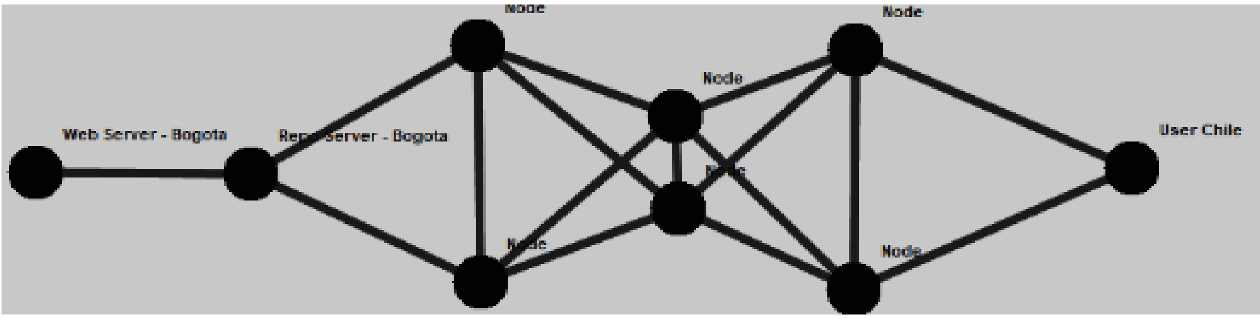
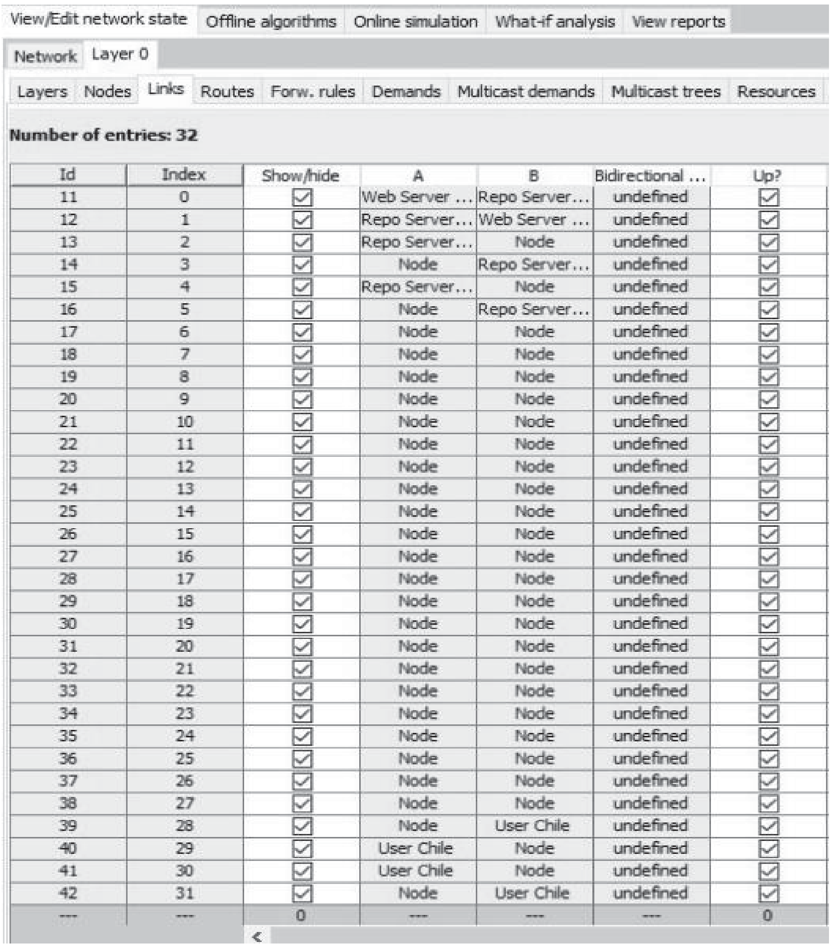


Fig. 8 Network design for the routing of medical images– Net2plan



Id	Index	Show/hide	A	B	Bidirectional ...	Up?
11	0	☑	Web Server ...	Repo Server...	undefined	☑
12	1	☑	Repo Server...	Web Server ...	undefined	☑
13	2	☑	Repo Server...	Node	undefined	☑
14	3	☑	Node	Repo Server...	undefined	☑
15	4	☑	Repo Server...	Node	undefined	☑
16	5	☑	Node	Repo Server...	undefined	☑
17	6	☑	Node	Node	undefined	☑
18	7	☑	Node	Node	undefined	☑
19	8	☑	Node	Node	undefined	☑
20	9	☑	Node	Node	undefined	☑
21	10	☑	Node	Node	undefined	☑
22	11	☑	Node	Node	undefined	☑
23	12	☑	Node	Node	undefined	☑
24	13	☑	Node	Node	undefined	☑
25	14	☑	Node	Node	undefined	☑
26	15	☑	Node	Node	undefined	☑
27	16	☑	Node	Node	undefined	☑
28	17	☑	Node	Node	undefined	☑
29	18	☑	Node	Node	undefined	☑
30	19	☑	Node	Node	undefined	☑
31	20	☑	Node	Node	undefined	☑
32	21	☑	Node	Node	undefined	☑
33	22	☑	Node	Node	undefined	☑
34	23	☑	Node	Node	undefined	☑
35	24	☑	Node	Node	undefined	☑
36	25	☑	Node	Node	undefined	☑
37	26	☑	Node	Node	undefined	☑
38	27	☑	Node	Node	undefined	☑
39	28	☑	Node	User Chile	undefined	☑
40	29	☑	User Chile	Node	undefined	☑
41	30	☑	User Chile	Node	undefined	☑
42	31	☑	Node	User Chile	undefined	☑
---	---	0	---	---	---	0

Fig. 9 Links and nodes established in Net2plan

The configuration for the capacity of each link and traffic demand was conducted considering the specifications of the telemedicine systems, its performance evaluation through the QoS tests and that the system provides the routing service for 40MB medical images. Additionally, the distance between each of the nodes was configured, ensuring that it approximates the real value and thus, being able to obtain more precise results.

Once the parameters and specific network designs were defined, the implementation of the routing algorithms was made. For this, we used the pseudo-code established in the description of the algorithms and we conducted the modeling based on the Java Optimization Modeler libraries integrated in the Net2plan tool. Said libraries allowed the development of the algorithms with a high syntaxes level based in Java.

Subsequently, we implemented the Tabu Search algorithm on the network design, where we considered its own parameters, as shown in Table I.

Once the Tabu Search algorithm was successfully executed, we implemented the Simulated Annealing algorithm, likewise the own parameters from this algorithm are considered, as shown in Table II.

TABLE I
PARAMETERS OF TABU SEARCH

Parameter	Value	Description
Maximum Execution Time (s)	60	Maximum algorithm execution time
Aspiration Criterion	Yes	The Aspiration Criterion is enabled
Initialization Type	Random	Algorithm initialization type
Maximum Number Iterations	15000	Maximum number of iterations of the algorithm
Maximum Number Iterations Non-Improving	10	Maximum number of iterations before the improvement of the solution, to restart randomly
Tabu List Size	110	Size of the tabu list

s = seconds

TABLE II
PARAMETERS OF SIMULATED ANNEALING

Parameter	Value	Description
Maximum Execution Time (s)	60	Maximum algorithm execution time
Freezing Probability Threshold	0.05	If the fraction of iterations with a jump in the internal cycle is less than this value, the system overheats. If not, geometric reduction.
Geometric Reduction Factor	0.6	Geometric decrease factor of the temperature
Initial Acceptance Probability	0.4	Probability of acceptance of a worst case
Maximum Number Iterations Inner Loop	5000	Number of Iterations of Inner Loop
Maximum Number Iterations outer Loop	30	Number of Iterations of Outer Loop
Initialization Type	Random	Algorithm initialization type

s = seconds

VI. RESULTS

In the test scenario and the characterization of the Bogotá-Chile channel, we conducted the corresponding monitoring of the upload and download of medical images with the Wireshark tool, where we considered the origin IP, time, number and size of the package. Based on the obtained results, we obtained the QoS metrics for their subsequent analysis.

As mentioned before, said tests were conducted for 10 consecutive minutes, thus obtaining different results regarding the QoS metrics for each package. Once we obtained the results, we calculated the average to determine the behavior and optimal performance of the service.

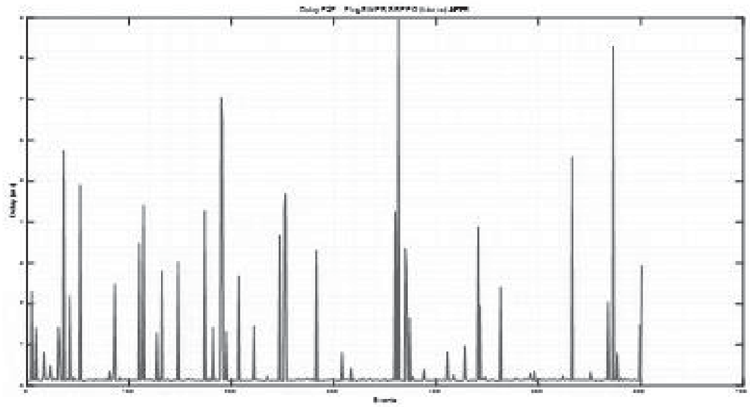
Said data and average were organized in Excel tables (Fig. 10).

Tamaño del	Ip destino	# de Secuencia	Tiempo de vida (ttl)	Tiempo (ms)	Delay E2E (ms)	Latency (ms)	Jitter (ms)	Throughput Instantaneo (bps)
32	190.60.233.52	1	55	46	23,000	23,000	0,000	0,0000217
32	190.60.233.52	2	55	31	15,500	30,750	15,250	0,0000645
32	190.60.233.52	3	55	53	26,500	39,583	13,083	0,0000566
32	190.60.233.52	4	55	29	14,500	43,208	28,708	0,0001379
32	190.60.233.52	5	55	57	28,500	48,908	20,408	0,0000877
32	190.60.233.52	6	55	11	5,500	49,825	44,325	0,0005455
32	190.60.233.52	7	55	10	5,000	50,539	45,539	0,0007000
32	190.60.233.52	8	55	19	9,500	51,727	42,227	0,0004211
32	190.60.233.52	9	55	28	14,000	53,282	39,282	0,0003214
32	190.60.233.52	10	55	53	26,500	55,932	29,432	0,0001887
32	190.60.233.52	11	55	24	12,000	57,023	45,023	0,0004583
32	190.60.233.52	12	55	17	8,500	57,732	49,232	0,0007059
32	190.60.233.52	13	55	15	7,500	58,309	50,809	0,0008667
32	190.60.233.52	14	55	31	15,500	59,416	43,916	0,0004516
32	190.60.233.52	15	55	32	16,000	60,482	44,482	0,0004688
32	190.60.233.52	16	55	61	30,500	62,389	31,889	0,0002623
32	190.60.233.52	17	55	46	23,000	63,742	40,742	0,0003696
32	190.60.233.52	18	55	54	27,000	65,242	38,242	0,0003333
32	190.60.233.52	19	55	38	19,000	66,242	47,242	0,0005000
32	190.60.233.52	20	55	36	18,000	67,142	49,142	0,0005556
32	190.60.233.52	21	55	23	11,500	67,689	56,189	0,0009130
32	190.60.233.52	22	55	55	27,500	68,939	41,439	0,0004000

Fig. 10 Collection of obtained QoS metrics and averages from the tests scenarios

Due to the duration of the tests, we were able to graph the QoS metrics for each sent and received package at different moments in time, guaranteeing that the values remained in acceptable ranges, verifying an efficient connectivity in the measured channel. Said graphs were made using the Matlab tool (Figs. 11 and 12).

Delay E2E



Latency

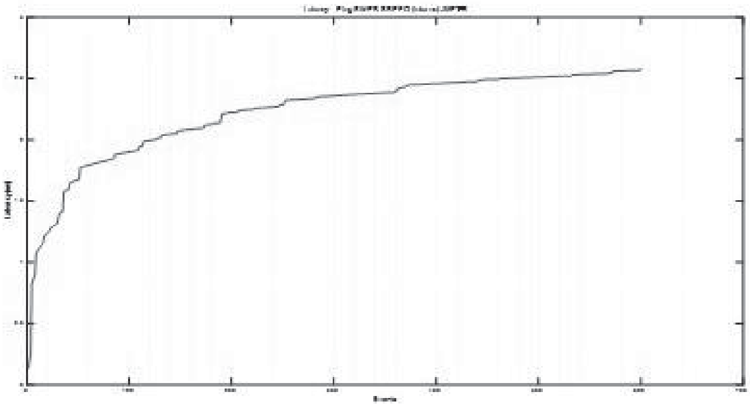


Fig. 11 Plot metrics for QoS obtained from the test scenarios

Jitter

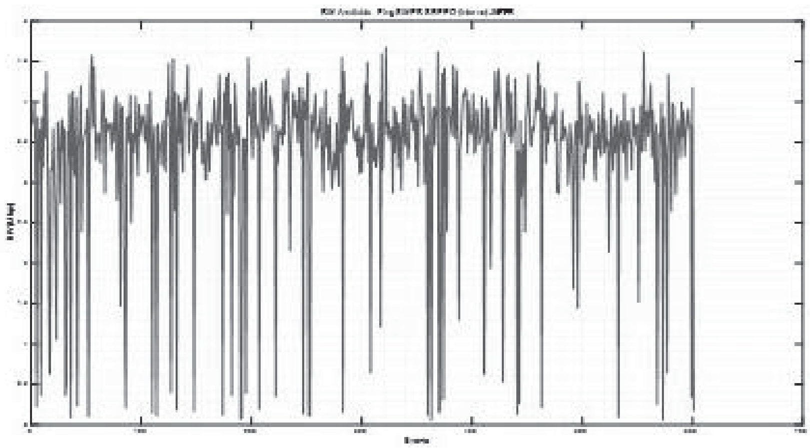


Fig. 12 Plot metrics for QoS obtained from the test scenarios

With the purpose of showing and analyzing the results from each of the tests scenarios, the averages are summarized in the following tables.

A. Results of Test Scenario 1

Table II shows the behavior in scenario one, where two different tests were conducted. The first one analyzed the behavior of the QoS metrics between the local users and the repository service and the second one analyzed the behavior between the web server and the repository server. In the two tests, we could observe that in the conditions form this scenario, the telemedicine system presents an excellent performance, which allows us to guarantee that both the connectivity, and the availability and integrity criteria were efficiently fulfilled.

TABLE III
RESULTS OF TEST SCENARIO 1

QoS Metric	Test 1	Test 2
Delay (ms)	0,354	0,497
Latency (ms)	2,225	2,198
Jitter (ms)	2,054	1,814
Instant throughput (bps)	1,003	0,969
General throughput (bps)	723579,457	637024,564

ms = milliseconds, bps = bit per second

B. Results of Test Scenario 2

Table IV shows the behavior from the second scenario, where we conducted 2 different tests. The first one analyzed the behavior of the QoS metrics between the remote users and the repository server and the second one analyzed the behavior between the web server and the repository server.

In the first test we could observe that, under the conditions from this scenario, the telemedicine service doesn't present an optimal behavior, whereby, the availability and integrity criteria cannot be guaranteed. In this scenario, we need to implement routing algorithms that will allow a more efficient fulfillment within this system, since the expected behavior from remote users was not obtained.

When evaluating the behavior of the second test, an optimal performance was determined, guaranteeing that both the connectivity, and the availability and integrity criteria were fulfilled efficiently between the servers.

TABLE IV
RESULTS OF TEST SCENARIO 2

QoS Metric	Test 1	Test 2
Delay (ms)	19,263	0,412
Latency (ms)	115,241	2,747
Jitter (ms)	96,158	2,491
Instant throughput (bps)	0,012	0,893
General throughput (bps)	6644,748	621401,957

ms = milliseconds, bps = bit per second

C. Results of Test Scenario 3

Table V shows the behavior from the third scenario, where 3 different tests were conducted. The first test analyzed the behavior of the QoS metrics between the local users and the repository server, the second one analyzed the behavior between the web server and the repository server and the third one analyzed the behavior between the remote users and the repository server.

In the same way that in the previous tests, we were able to conclude that for local users, the QoS metrics behave in an optimal way, however, with remote users, the expected behavior is not met, which confirms the need to implement routing algorithms to improve the behavior from the telemedicine system when the upload an download is made by remote users.

TABLE V
RESULTS OF TEST SCENARIO 3

QoS Metric	Test 1	Test 2	Test 3
Delay (ms)	0,347	0,933	7,030
Latency (ms)	2,208	5,543	42,333
Jitter (ms)	1,906	4,887	35,303
Instant throughput (bps)	0,589	0,777	0,023
General throughput (bps)	737431,081	274505	18207,68

ms = milliseconds, bps = bit per second

D. Results for the Channel Characterization

Tables VI-IX show the results for the channel characterization between the repository server located in Bogotá, Colombia and the remote user in Santiago de Chile, Chile. Said tests were implemented at different times of the day, analyzing the upload and download of medical images. This characterization determined that the channel presents a better behavior regarding the QoS metrics when the upload of images is done in the afternoon, since there is less traffic intensity, a factor to be considered for the network characterization for the implementation of algorithms.

TABLE VI
RESULTS OF TEST SCENARIO 4 – TCP

QoS Metric	Load (8:00am)	Load (8:30am)	Download (8:00am)	Download (8:30am)
Delay (ms)	2,658	3,367	2,433	1,549
Latency (ms)	210,280	212,669	34,6127	699,062
Jitter (ms)	209,859	213,932	35,6692	697,512
Instant throughput (bps)	2299	499,140	558,790	503,916
General throughput (bps)	2126789,54	2158190,843	3599678,83	4833803,527

ms = milliseconds, bps = bit per second

TABLE VII
RESULTS OF TEST SCENARIO 4 – HTTP

QoS Metric	Load (8:00am)	Load (8:30am)	Download (8:00am)	Download (8:30am)
Delay (ms)	0,003	0,0046	64,195	116,525
Latency (ms)	0,003	0,0046	0,549	116,305
Jitter (ms)	0,487	0,26173	64,182	47,370
Instant throughput (bps)	1179,869	262,321	440,346	363,855
General throughput (bps)	8905416,33	12561457,92	70079,88447	65043,290

ms = milliseconds, bps = bit per second.

TABLE VIII
RESULTS OF TEST SCENARIO 4 - TCP

QoS Metric	Load (11:30pm)	Load (12:00pm)	Download (11:30pm)	Download (12:00pm)
Delay (ms)	84,725	70,687	752,017	43,184
Latency (ms)	84,725	70,687	752,799	43,874
Jitter (ms)	84,46	70,121	704,979	117,631
Instant throughput (bps)	1445,58	920,447	679,832	83,094
General throughput (bps)	3606809,61	4366994,966	4484671,637	2017546,706

ms = milliseconds, bps = bit per second.

TABLE IX
RESULTS OF TEST SCENARIO 4 - HTTP

QoS Metric	Load (11:30pm)	Load (12:00pm)	Download (11:30pm)	Download (12:00pm)
Delay (ms)	0,023	0,012	0,991	12,191
Latency (ms)	0,023	0,012	0,987	0,540
Jitter (ms)	0,310	0,312	75,507	12,094
Instant throughput (bps)	294,139	174,665	344,920	199,009
General throughput (bps)	14878311,093	1267705,302	73151,996	411796,071

ms = milliseconds, bps = bit per second.

TABLE X
RESULTS OF TEST SCENARIO 4 - TCP

QoS Metric	Load (4:20pm)	Load (4:50pm)	Download (4:20pm)	Download (4:50pm)
Delay (ms)	6,650	38,028	686,500	72,365
Latency (ms)	128,181	189,887	45,569	165,626
Jitter (ms)	128,531	203,561	657,807	159,255
Instant throughput (bps)	1240,327	1085,538	4,161	269,212
General throughput (bps)	3108872,792	5015812,268	1081329,723	2657486,009

ms = milliseconds, bps = bit per second.

TABLE XI
RESULTS OF TEST SCENARIO 4 - HTTP

QoS Metric	Load (4:20pm)	Load (4:50pm)	Download (4:20am)	Download (4:50am)
Delay (ms)	0,3709	0,363	37,142	59,691
Latency (ms)	0,0393	0,016	0,447	2,690
Jitter (ms)	0,3698	0,356	36,901	59,259
Instant throughput (bps)	200,7942	158,988	98,836	139,169
General throughput (bps)	1259467,234	11387461,459	124413,112	73906,078

ms = milliseconds, bps = bit per second

E. Evaluation and Comparison of the Routing Algorithms

In the simulation of the routing algorithms, both for the Simulated Annealing and the Tabu Search, it was observed that there wasn't a loss percentage in the traffic. Additionally, through the Net2plan tool, we obtained network reports, which allowed to analyze the behavior of the QoS metrics for both algorithms.

Regarding the delay, latency and jitter, we could observe that both algorithms presented an efficient behavior, where the results were similar to the ideal values found in scenario 1. However, during all tests, it was observed that the Tabu Search algorithm presented a better behavior (Figs. 13-15).

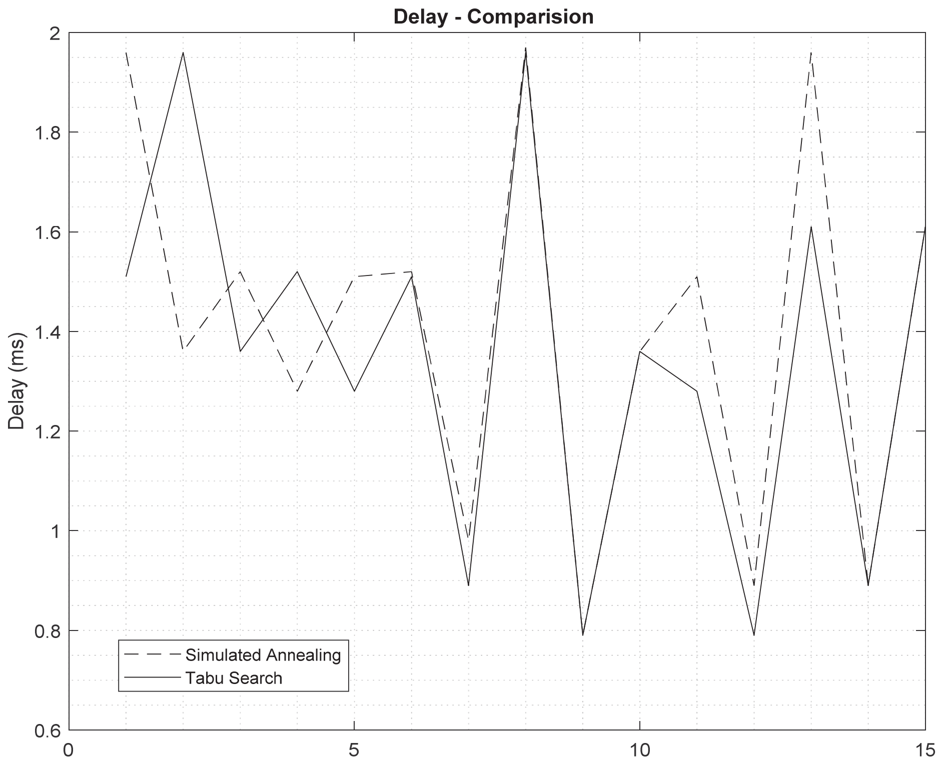


Fig. 13 Comparison of the delay behavior from the routing algorithms

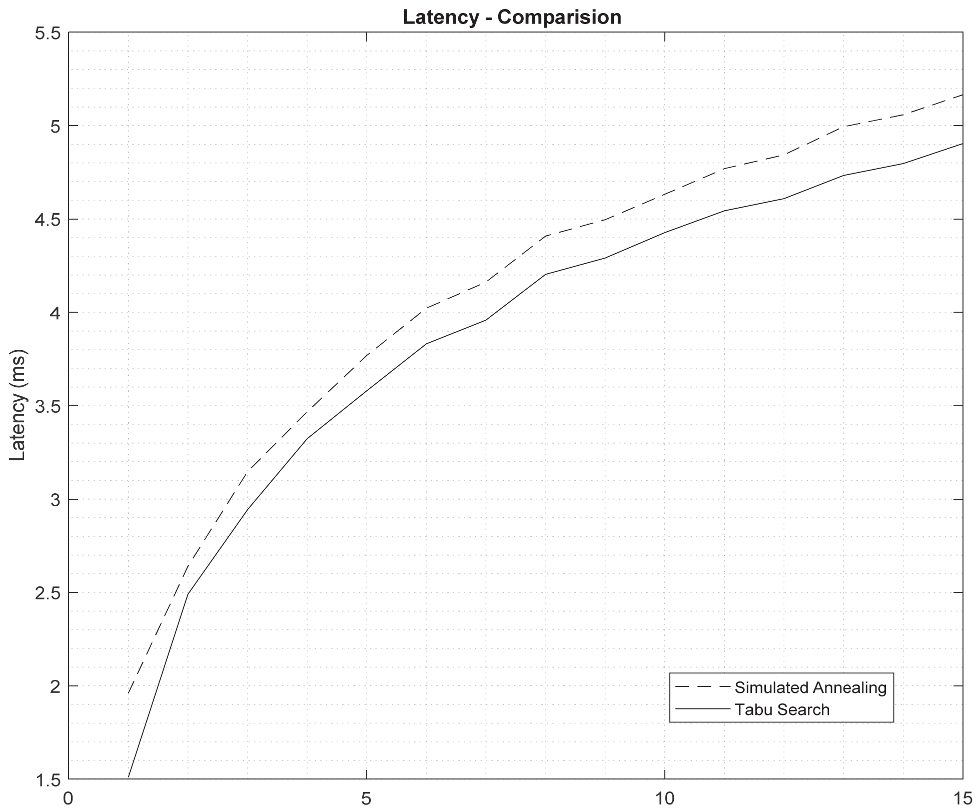


Fig. 14 Comparison of the latency behavior from the routing algorithms

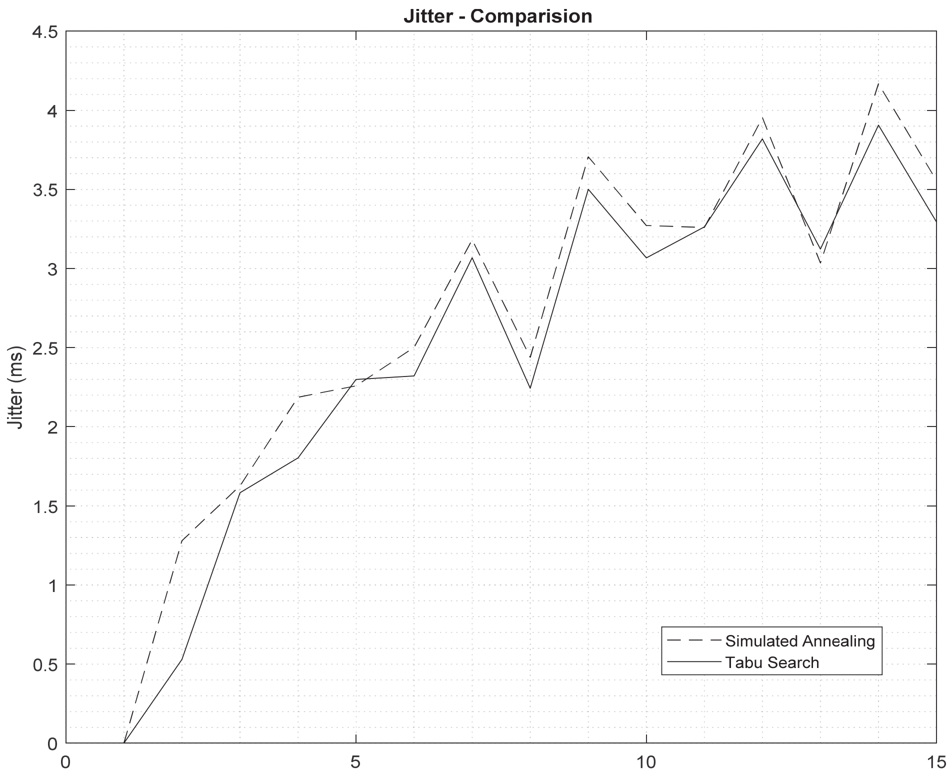


Fig. 15 Comparison of the jitter behavior from the routing algorithms

This result determined that said algorithm provides a better fulfillment of the specific criteria from this study and improves the quality of its service.

Through the evaluation of the throughput, we observed that both algorithms presented an optimal behavior, however, an existence of peaks was observed during the tests, where Simulated Annealing passed Tabu Search, but in general, the Tabu Search algorithm presented a better behavior and performance (Fig. 16).

It was determined that Tabu Search had a greater success rate for the packages, in other words, that it guaranteed a better fulfillment of the specific criteria for the type of data we are handling in this study.

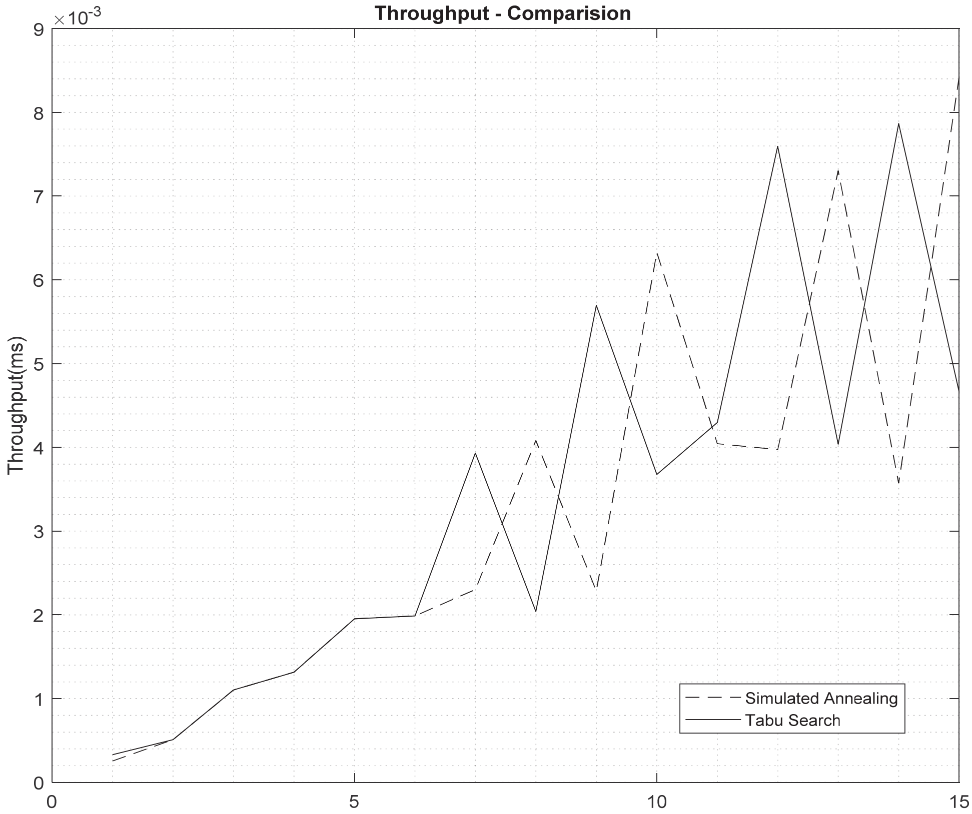


Fig. 16 Comparison of the throughput behavior from the routing algorithms

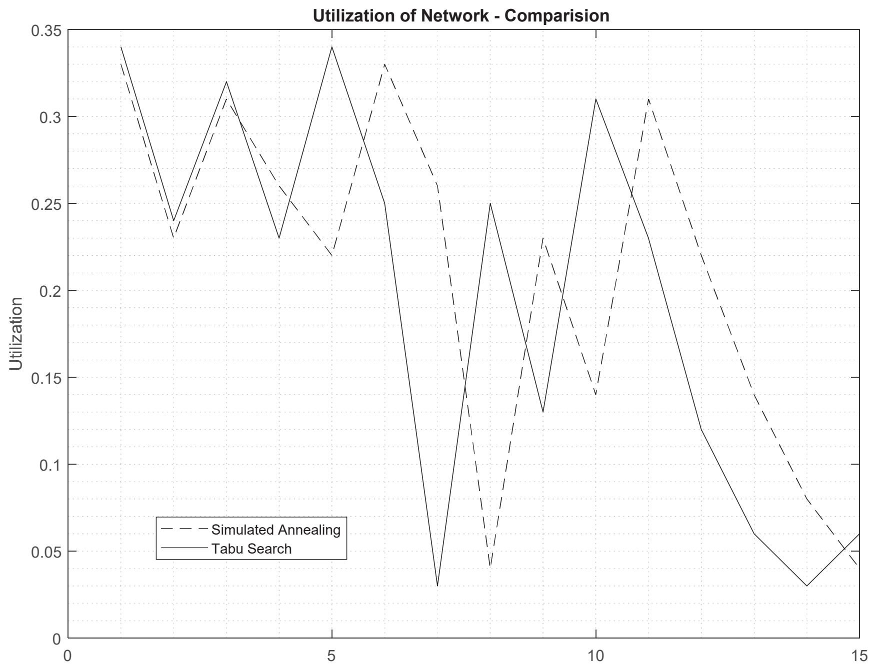


Fig. 17 Comparison of the network use behavior for the routing algorithms

Finally, we analyzed the network use for each of the algorithms, thus observing that in the same way that in the previous metrics, Tabu Search presented a better performance. This since the Simulated Annealing required a greater quantity of jumps in the search for solutions, thus presenting a greater use of the network resources (Fig. 17), therefore determining that Tabu Search guarantees a greater network availability and improves its performance.

Subsequently, we observed the results from a numerical perspective, we calculated the corresponding average and we tabulated them in Table XII.

TABLE XII
RESULTS OF COMPARISON ALGORITHMS

QoS Metric	Tabu Search	Simulated Annealing
Delay (ms)	1,355	1.393
Latency (ms)	3.876	4.102
Jitter (ms)	2.521	2.695
Throughput (bps)	0.0034	0.0033
Utilization	20%	21%

ms = milliseconds, bps = bit per second

These results confirm the graphic analysis, in other words, we observe that the Tabu Search algorithm passed the Simulated Annealing in all the evaluated QoS metrics.

VII. CONCLUSIONS

The telemedicine service from the TIGUM group presented a good performance regarding the QoS metrics when the users connected in a local way, thus guaranteeing the availability and integrity criteria in the upload and download of medical images only for certain users. Therefore, it is necessary to find solutions for said issue, such as the implementation of heuristic algorithms.

Heuristic algorithms are an optimal solution for the improvement of the upload and download of medical images in a telemedicine system for remote users. In other words, that any user, not matter his location can access the images, this since said algorithms find routes faster, keeping the optimal fulfillment levels for the specific criteria established for this type of information. Said algorithms are necessary to improve the behavior of the QoS metrics, thus guaranteeing that the service is provided more efficiently and becomes an actual support for health entities.

The heuristic Tabu Search presented a better behavior regarding the QoS metrics compared to the Simulated Annealing algorithm, confirming that Tabu Search determines, in a better way, parameters such as speed, efficiency, reliability and stability of the service. The compliance with said parameters ensures that the availability and integrity criteria, characteristic of clinical information are fulfilled in an optimal way. Additionally, this algorithm presented a lower network use compared to the Simulated Annealing, resulting in a decrease of the use of network resources, which allows us to conclude that Tabu Search can be implemented in this type of infrastructures and will not present saturation incidents, improving the availability and service.

Finally, it is important to mention that both algorithms evaluated in this study, present minimum differences in their results, which is why it is necessary to continue the research and evaluation of other heuristic and meta-heuristic algorithms to obtain more significant differences and accomplish a better performance in the efficiency of telemedicine infrastructures, regarding the routing of medical images as a service.

ACKNOWLEDGMENT

This Project has been funded by the Office of the Vice Rector for Research at Universidad Militar Nueva Granada – Project code: IMP-ING-2660.

REFERENCES

[1] Babulak, E. (2006). Quality of service provision assessment in the healthcare information and telecommunications infrastructures. International journal of medical informatics, 75(3-4), 246-252.
[2] Shaikh, A., Misbahuddin, M., & Memon, M. S. (2008, April). A system design for a telemedicine health care system. In International Multi Topic Conference (pp. 295-305). Springer, Berlin, Heidelberg.
[3] Oddershede, A., & Carrasco, R. (2010, July). Methodology to evaluate and improve the QoS ICT networks in the healthcare service. In Communication Systems Networks and Digital Signal Processing (CSNDSP), 2010 7th International Symposium on (pp. 871-875). IEEE.
[4] Basalo, P. M. R. (2010). Algoritmos heurísticos y aplicaciones a métodos formales (Doctoral dissertation, Universidad Complutense de Madrid).
[5] Moreno, L. F., Díaz, F. J., Peña, G. E., & Rivera, J. C. (2007). Análisis comparativo entre dos algoritmos heurísticos para resolver el problema de planeación de tareas con restricción de recursos (RCPSP). Dyna, 74(151), 171-183.
[6] Skorin-Kapov, N. (2006). Heuristic algorithms for the routing and wavelength assignment of scheduled lightpath demands in optical networks. IEEE Journal on Selected Areas in Communications, 24(8), 2-15.
[7] Goścień, R., Walkowiak, K., & Klinkowski, M. (2015). Tabu search algorithm for routing, modulation and spectrum allocation in elastic optical network with anycast and unicast traffic. Computer Networks, 79, 148-165.
[8] Rodríguez, A. B., & Saavedra, F. (2010). Optimización del algoritmo genético para la solución integral de enrutamiento en redes fotónicas. Información tecnológica, 21(3), 125-133.
[9] Rodríguez, A., Saavedra, F., & Ramírez, L. (2011). Simulated Annealing una Propuesta de Solución al Problema RWA en Redes Fotónicas. In Proceedings of XVIII Congreso Internacional De Ingeniería Eléctrica, Electrónica, Sistemas Y Ramas Afines (IEEE InterconUNI).
[10] Castro, A., Velasco, L., Ruiz, M., Klinkowski, M., FernáNdez-Palacios, J. P., & Careglio, D. (2012). Dynamic routing and spectrum (re) allocation in future flexgrid optical networks. Computer Networks, 56(12), 2869-2883.
[11] Bhaskaran, K., Triay, J., & Vokkarane, V. M. (2011, June). Dynamic anycast routing and wavelength assignment in WDM networks using ant colony optimization (ACO). In Communications (ICC), 2011 IEEE International Conference on (pp. 1-6). IEEE.
[12] Triay, J., & Cervello-Pastor, C. (2010). An ant-based algorithm for distributed routing and wavelength assignment in dynamic optical networks. IEEE journal on selected areas in communications, 28(4).
[13] Pham, D., & Karaboga, D. (2012). Intelligent optimisation techniques: genetic algorithms, tabu search, simulated annealing and neural networks. Springer Science & Business Media.
[14] Pavon-Marino, P D. (2012). Algoritmos de tipo búsqueda tabú (tabu search) para el diseño de un encaminamiento con protección 1+1 Escuela técnica superior de ingeniera en telecomunicación.
[15] Pavon-Marino, P D. (2012). Algoritmos de enfriamiento simulado (simulated annealing) Escuela técnica superior de ingeniera en telecomunicación.
[16] Fernández Gambín, A. (2015). Desarrollo de casos de estudio sobre la herramienta de planificación de redes Net2Plan.